CALIFORNIA. DEPT. OF WATER RESOURCES.
BULLETIN.

STATE OF CALIFORNIA
The Resources Agency
Department of Water Resources

BULLETIN No. 151-67

WATER
A Progress Report

SEPTEMBER 1968

RONALD REAGAN
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State of California

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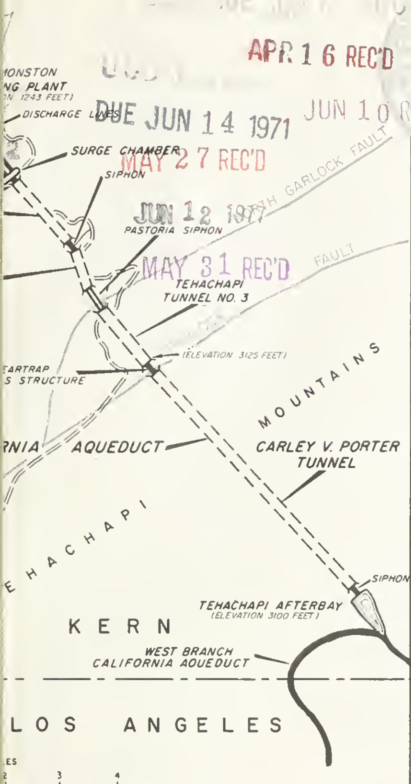
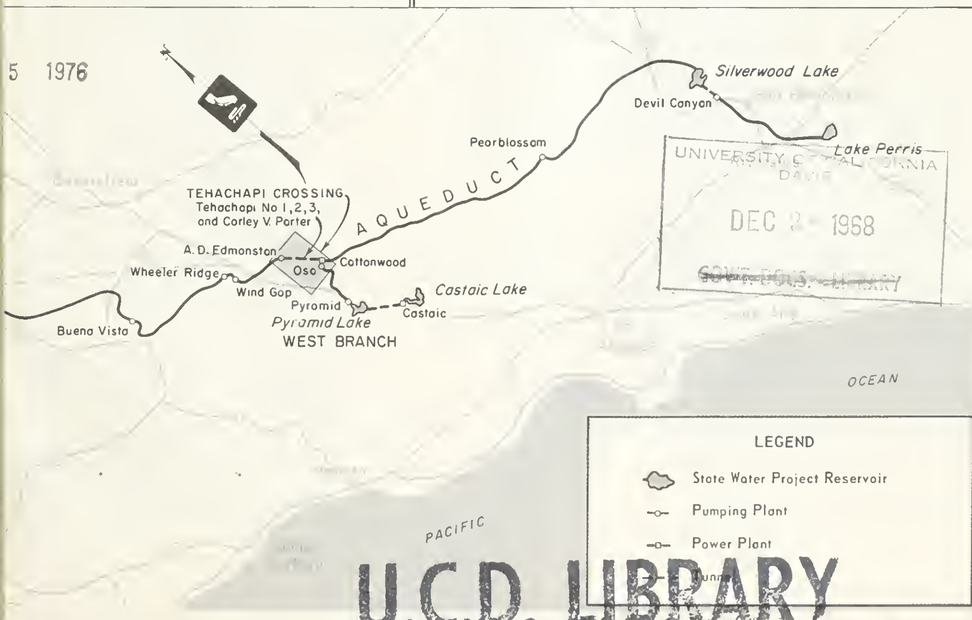


The Tehachapi Crossing
(See page 19)



FOREWORD

Water must move from source to user, and it must be stored for use when needed. This is the business of California's Department of Water Resources. This is the subject of this report.

Nature provides much of the water movement and storage in California. Rivers and streams transport water from snow-clad and rain-drenched highlands to largely arid inland valleys and thirsty coastal cities. Underground reservoirs, called aquifers, store enormous quantities of water—ground water—which can be used by man today, next year, next decade, or next century.

Water resources technologists measure snowfall and rainfall and river and stream flow and chart the quantities and movement of ground water. They measure the quality of water in lakes, rivers, streams, and ground. They predict the quality and quantity of California's water resources and the water requirements of her citizens this year and in years to come.

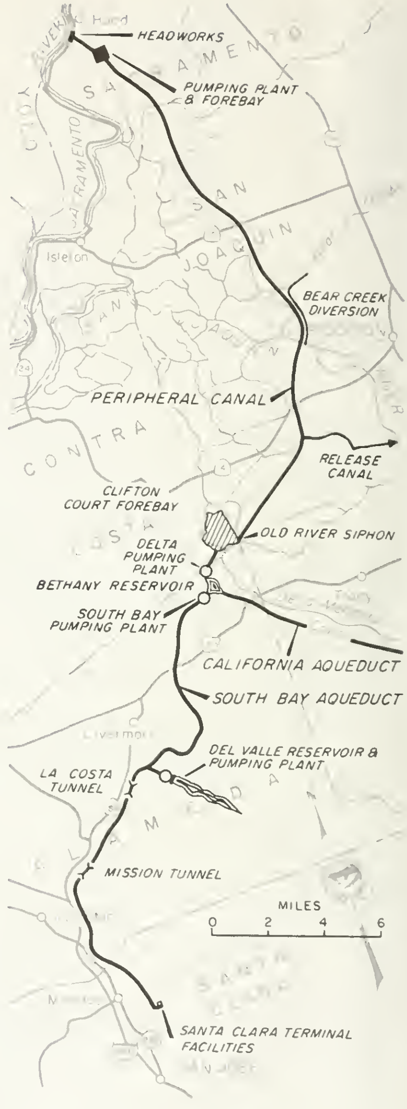
Much of the water used by Californians must be stored and transported by means of man-made structures—dams, aqueducts, tunnels, pumps, and pipelines. These structures are planned, designed, built, and operated by the hundreds of water agencies throughout the state and by agencies of the federal government. The California Department of Water Resources coordinates the work of other water agencies and directs the most comprehensive water development project yet undertaken by man—the State Water Project.

The following pages tell of some of the challenges and accomplishments of the planners, designers, builders, and operating personnel of the Department. Some of the story is detailed; some is only sketched; some is saved for future telling. A vital chapter in tomorrow's story of water resources development in California undoubtedly will be one called "Seawater Conversion." A number of seawater conversion techniques today are competing for acceptance by the water agencies of California and of seacoast lands throughout the world.

The wisdom of yesterday's water resources planners is reflected today in earth and rock embankments, concrete and steel, and flowing water. Wise planning and management today and tomorrow will ensure the water supply needed for California's farms, factories, and people tomorrow and the day after tomorrow.

W R Gianelli

WILLIAM R. GIANELLI
Director
Department of Water Resources



WATER from the Sacramento River will flow through the Peripheral Canal along the eastern edge of the Delta to Clifton Court Forebay. From there, the Delta Pumping Plant will pump the water into Bethany reservoir for release to the California Aqueduct and, via the south Bay Pumping Plant, to the South Bay Aqueduct.

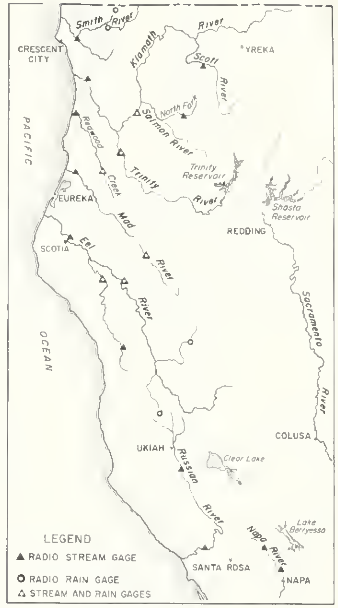
DATA: Tool of Forecasting

When will a flood strike? How will the ground move under State Water Project aqueducts? What is the relation between snowpack and water supply? By measurement of river heights and rainfall, by the science of precision distance measurement, by the fortitude of skiers trekking to the snow country, the Department of Water Resources finds answers to these questions.

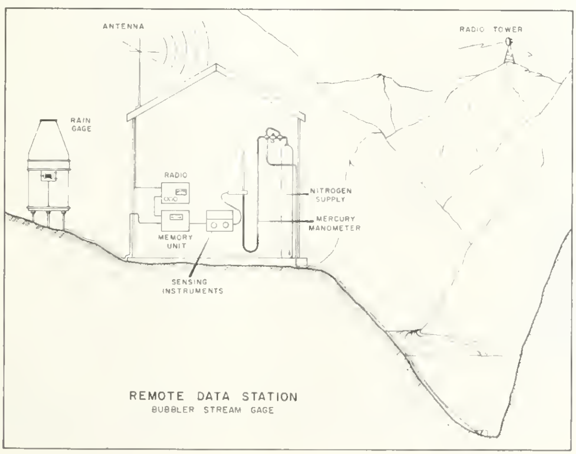
Current river height and rainfall information from the flood-prone north coast areas of California speeds to analysts in the Department of Water Resources by means of a network of telemetering stations. These stations contain equipment that automatically measures river stages and rainfall and transmits the data by radio to a distant receiver. Just as someone in Houston can discover, via telemetry, what the temperature is aboard an unmanned space vehicle, so also can the Department of Water Resources interrogate, by remote control from Sacramento and Eureka, 23 flood data stations strategically placed throughout California's major north coast watersheds. Heights of rivers and depths of rainfall are reported from these stations and relayed via radio towers either to consoles on the 16th floor of the Resources Building in Sacramento or to the Department office in Eureka. Both offices are part of the Flood Operations Center maintained jointly with the U. S. Weather Bureau. The high-speed telemetry system began operation in 1966.

The high-speed system, designed to warn of flood, was itself born of flood. The 350-mile strip between Marin County and the Oregon line is one of the wettest in the country: in the Eel River, at the peak of the December flood of 1964, more than 5½ million gallons of water flowed past the town of Scotia each second. The high waters that year destroyed or damaged the instruments of an earlier gaging and telemetry system that, with its well houses in the stream, was more vulnerable. The earlier system was replaced with the new high-speed system. Now the new stations can be interrogated in four minutes, compared with 40 minutes for the stations in the Sacramento and San Joaquin valleys that are still on the slow network.

Flood data bulletins are issued about four times a day during high-water periods. They go out by telephone and teletype circuits to public and private agencies and to newspapers and television and radio stations.



FLOOD WARNING NETWORK along California's North Coast gives early notice of impending high waters threatening cities and farms downstream from areas of heavy rainfall. Two or more telemetered river gages are installed in each of the seven major watersheds in the North Coastal area, except for the Smith River Basin, which has one.



BUBBLER STREAM GAGE automatically measures the height of a river. Nitrogen gas enters a tube leading to the river bottom and slowly bubbles out into the water. The other end of the tube is connected to a mercury manometer. As the river rises, the pressure on the nitrogen at the open end of the tube increases. The increasing nitrogen pressure pushes the mercury around the manometer elbow. The rise of the mercury in the left side of the manometer is noted by sensing instruments, and data on the movement is stored in a memory unit, which also stores rainfall data recorded by the rain gage. Data on both variables are transmitted by radio to Eureka or Sacramento.

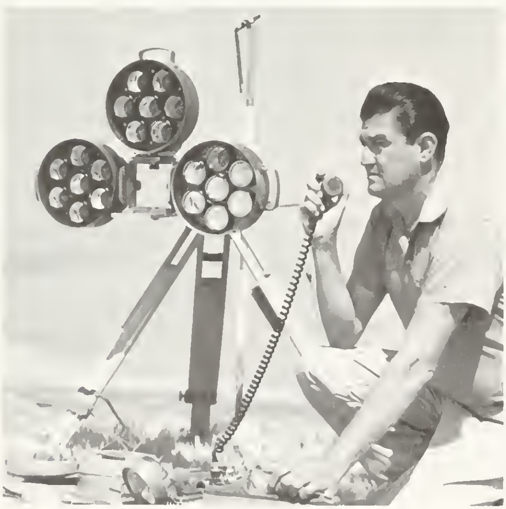
EARTHQUAKE

The San Francisco earthquake of 1906 was only one of more than half a dozen potentially destructive quakes (those with magnitudes of more than 7) that have shaken large areas of California in the last hundred years. Others might have been just as destructive had they occurred in areas of dense population. Within recorded history, California has had more of these large earthquakes than any other state except Alaska.

A large earthquake is caused by an abrupt and extensive displacement of rock along a fracture, or fault. The sudden heaving of large blocks of earth and the grating of rock as the faces of the fracture slip past each other shake the earth's crust as if it were an enormous rug—often toppling man's works more than 50 miles away.

Although an earthquake occurs over a large area and therefore may cause widespread damage, gradual slippage may also cause substantial damage as structures that cross a fault line are offset and broken. Much of the slippage along geologic fault lines in California causes no shaking that can be detected amid the louder cacophony of freeway rumbling, railroad rattling, and the pounding of the ocean surf. The gradual slip, or creep, may amount to only a few centimeters a year, compared with, for example, the 21 feet of abrupt displacement that occurred in seconds along the San Andreas fault in Marin County the morning of April 18, 1906.

MIRRORS reflect distance-measuring light beam.



Most geologic slips in California are horizontal, resulting in changes in the latitude and longitude of objects near the fault. If a rigid section of aqueduct crossed an active fault, a very small annual creep would, over a number of years, sever the aqueduct. Earth scientists believe that both creep and the abrupt displacement that causes large earthquakes will occur along the active faults of California during the next 100 years as they have occurred during the past 100 years. Aqueducts of the State Water Project, however, must cross these faults to deliver water to thirsty communities.

Engineers of the Department of Water Resources could design aqueducts to resist damage from earth slip. But they had to know which fault crossing had to be protected and how much protection was needed. To answer these questions, they had to know how much slippage was likely, over a number of decades, wherever an aqueduct had to cross a geologic fault. Probable future fault movements can be estimated from observations of past and current movements. These movements can now be monitored with great precision.

One way to monitor fault movement is to periodically measure the straight-line distance between two points on opposite sides of the fracture. A change in this distance indicates movement. Surveyors often arrange networks of lines to better determine the direction and amount of movement.

In 1963, the Department of Water Resources signed a contract with the U. S. Coast and Geodetic Survey for cooperative monitoring of all displacement, abrupt and gradual, at points on active faults where aqueducts of the State Water Project would cross. Under the contract, the Coast Survey established 21 networks, which, along with other Coast Survey networks, have been periodically measured.

The Coast Survey networks, however, do not provide all the data needed to tell the whole story of fault movement. In some places, the ground near a still-active fault appears resistant to slip, as if the fault were temporarily locked. In such cases, the stresses from within the planet distort the surface, bending it usually in the direction it would have moved if it could have slipped. Surveyors can satisfactorily detect this bending, also called crustal

P R E D I C T I O N

strain, only at some distance from the fracture, usually 3 to 5 miles.

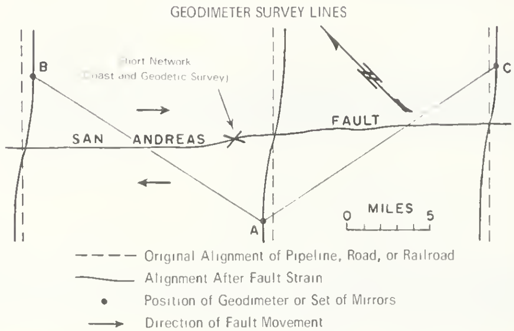
In the Coast Survey networks, the survey points are much closer to the fault. These networks can accurately measure slip, which can be observed only in the immediate vicinity of the fault (less than a mile), but to measure strain, much longer geodetic survey lines are needed.

More complete data on both slip and strain were needed for the routing and designing of State Water Project aqueducts. Acquisition of this data was facilitated by development of a device that promised precision in the measurement of distances of 12 to 20 miles across terrain often inaccessible to surveyors using conventional techniques. The device enables the operator to measure survey lines by noting the time it takes for a light beam to leave the instrument, at one mountain peak, reflect from a set of mirrors at another peak, and return. Tests have shown that this device, the Geodimeter, can be used to measure a 16-mile line to an accuracy of less than one centimeter.

The Geodimeter does not distinguish between slip and strain, but a shorter Coast Survey network in the same area will indicate any slip, and any difference between the distance change attributable to slip and the distance change measured by the Geodimeter is attributed to strain.

The basic group of lines for the Geodimeter was established in 1959, when some 60 lines were measured for the first time. The lines were concentrated on the State's greatest and best-known fault, the San Andreas, which must be crossed several times by aqueducts of the State Water Project. Movement along the San Andreas fault is to the right: to an observer on either side of the fault, objects on the other side move to the right.

These surveys have indicated that fault movement is greater along the San Andreas fault just south of Hollister than in any other area monitored. From 1959 to 1967, the average annual movement there was 4.4 centimeters. Comparison of Geodimeter data with Coast Survey data and displacement of man-made objects indicates that most of this activity was slip. Displacement at this rate adds up to nearly 8 feet in 50 years. Nearly the same annual amount of movement carries up into the San Francisco Bay area, where the movement is shared with the Calaveras and Hayward faults. South from Hollister, movement diminishes until it is almost indiscernible in the area where the San Andreas bends into a nearly east-west direction. Near San Bernardino, however, surveyors have found fault movement in the last two years where none had been observed before. This movement appears to be primarily strain.



EARTH STRAIN along a geologic fault may bend objects crossing the fault. This strain may be precisely determined by measuring the distances AB and AC with a Geodimeter. If AB shortens and AC lengthens, the movement will be as indicated. If the short network shows no movement (no offset is indicated), the movement shown by the Geodimeter data is attributed to strain. (The amount of strain is greatly exaggerated in the diagram.)

Continued surveys with the Geodimeter have indicated a possible relationship between variations in fault movement and the likelihood of a subsequent earthquake. Earthquakes with magnitudes of 4½ or more have been preceded by unusual line-length changes: reversal (shortening after a trend of lengthening, or vice versa) and acceleration or deceleration (change faster or slower than the trend). Just what causes these anomalies can only be conjectured. All that can be said now with certainty is that unusual line behavior sometimes precedes earthquakes. Often the anomalies appear to be related to shifting of movement from the main fault, when it locks, to a smaller fault. The evidence is far from complete, but a major discovery may result from the patient work of the people who measure fault slip and strain—a way to predict earthquakes.

Snow Runoff Prediction

As important to California as knowledge of rainfall and river stages is knowledge of water stored in the snowfields—the frozen reservoirs—of the Sierra Nevada. The snowfall during December through March in an average year accounts for more than 7 million acre-feet of runoff during the next 4 months —more than half the total April-July runoff. The melting snow throughout the spring and early summer supplies rivers and man-made reservoirs with water during a time of sparse precipitation.

How do we find out whether a year will be wet, dry, or normal? The best way the Department knows is to estimate how much water the Sierra snowpack will produce when it thaws. In making this estimate, as in monitoring flood conditions, the Department's newest system involves telemetry—radio transmission of data from remote, unmanned stations. Three pressure pillows, devices to measure snow water content, were installed by the U. S. Corps of Engineers in 1966 along the upper reaches of the Kings River east of Fresno. This was one of the first uses of unmanned snow-measurement stations in California. Data on the water content of the snow is telemetered to Sacramento daily during winter and spring. Similar snow sensors have shown promise at Mt. Hood.

At present, however, the use of remote snow sensors remains somewhat experimental. The Department relies heavily on more ordinary ways of measuring the water content of the Sierra's frozen reservoirs—ways like sending skiers to heights of 10,000 feet or more to weigh a sample of snow. For more than half a century men have climbed California's mountains carrying metal tubes to take samples of the snow. (A snow depth of 37 feet was once recorded near Mammoth Pass.) Snow surveying in California and Nevada began in 1909 when Dr. James E. Church, Jr., a University of Nevada professor and mountaineer, found places where the change in the amount of snow from one winter to the next was proportional to the change in the level of Lake Tahoe from one spring to the next. Establishing these index points, in mountain meadows that Dr. Church named "snow courses", is still the key to advance knowledge of next spring's runoff.

Every year, nearly 150 people take snow samples at more than 300 snow courses in California. The Snow Survey Program is a cooperative activity involving not only the Department of Water Resources, but 42 other public and private agencies.

On February 1, March 1, and May 1, snow surveyors are sent to key snow courses, while airborne photographers take pictures of some 100 snow-depth markers at other snow courses. On April 1, when knowledge of snow water content is more critical (time of maximum snowpack), all the snow courses are sampled.

Nevertheless, the time is near when the pressure pillow, or some other device, operating economically and without disturbing mountain primitive areas, will do much of the snow surveying work, not only to forecast supplies of water but also to forewarn of the threat of flood.

MT. ROSE SNOW SAMPLER, equipment like that used by Dr. Church, still remains the snow surveyor's basic tool. A two-man surveyor team may ski up to 15 miles and climb 7,000 feet in one day. On reaching a snow course, the men fit together 30-inch sections of the tube and drive the tube down through the snow. When the core of snow is raised, the bottom of the tube must contain traces of earth; if it doesn't, the surveyors will take a new sample, trying until they hit ground level. The surveyors then remove the snow-filled tube and attach it to a portable scale. An ounce of snow equals an inch of rainwater.

PLANNING

California has not had the severe water supply problems that have plagued other states with far greater water resources. Why?

PLANNING

The people of California will continue to have water when and where they need it. Why?

PLANNING

Planning is the first of four big steps in bringing a water project to fruition:

PLANNING **DESIGN** **CONSTRUCTION** **OPERATION**

Based on the water resources data of yesterday and today, planning probes and molds the tomorrow of California's water development. Planning looks forward to ways of meeting the water needs of next year—next decade—next century.

Water will be available in California to supply the State's needs for at least the next 60 years. Future needs for and availability of water are shown in DWR Bulletin No. 160–66, "Implementation of the California Water Plan". The plan is being implemented today by local, state, and federal agencies. As parts of this plan, several units of the federal Central Valley Project have been completed and in operation for a number of years; more are being developed.

The State Water Project, the world's largest single water development project, was planned to conserve and deliver 4.23 million acre-feet of water annually to meet the demands for water throughout much of California until 1990. Beyond 1990, water from the North Coastal streams will maintain the minimum project yield, even as developing areas in the Central Valley require more and more water to satisfy their own needs. The first North Coastal facility of the project will be the Middle Fork Eel River Development.

Much of the project planning accomplished by the Department is being implemented by local agencies.

Statewide Planning

Water Project planning begins 10 to 25 years before water delivery. So as to meet the water needs of California beyond 1990, the Department of Water Resources lays its plans today. Such plans laid today try to answer the questions of tomorrow:

- How many people will the year 2020 find in California?
- Where will these people live?
- How much water will the great cities need?
- The farms, the orchards, the vineyards—how much water will they need?
- How will California maintain its water quality?
- What farmlands will cities swallow?
- Into what new areas will irrigation waters flow?
- In what combinations do we develop surface water, ground water, desalinated water, reclaimed waste water?
- How do we deliver water from its source to the faucet?
- When do we begin the plan, the design, the construction?
- What will be the cost?
- How will the cost be financed?
- How much will water users pay?

These questions can be answered today not with the certainty of fact but by the wise estimation of probability. Today's water development planning is based on the best estimates we can make of future population, future economies, and future water requirements.

The expected increase in California population is from the present 20 million people to about 35 million in 1990 and to more than 50 million in 2020. These additional millions not only will use more water but also will use that water differently. Although agriculture will continue to use the most water, municipalities and industry will increase their use much more rapidly; such use will probably double by 1990 and quadruple by 2020.

Water use in nearly every section of California affects water planning in most other sections of the State. The population increase in Los Angeles County will affect the size of reservoirs inland from the northern coast of California. The construction of reservoirs on the Eel River to meet statewide water needs will help to resolve local flood control problems.

Today, the Department of Water Resources is estimating future water requirements for each area of the State.

Peripheral Canal

The Sacramento River pours fresh water into the northern end of the Sacramento-San Joaquin Delta. Supplemented by the San Joaquin River from the south, the Sacramento River flow winds through an intricate network of waterways which covers more than 400 square miles. At the southern end of the Delta, some 35 miles away, the Delta Pumping Plant pumps water into the South Bay and California Aqueducts.

Salt water from San Francisco Bay invades the western Delta through Suisun Bay, and during high tides presses upstream against the river and channel flow. Historically, salt water has intruded to degrade all but the river outlet areas into the Delta. In recent years, releases from Shasta Dam have reduced the salt water intrusion into the Delta.

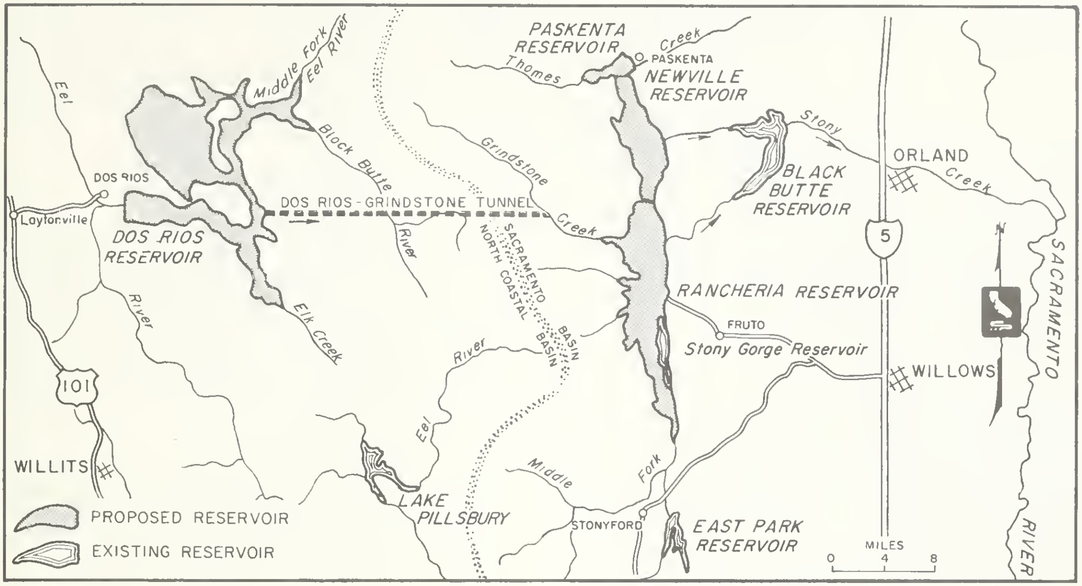
Complicating the natural battle of fresh versus salt water within the Delta are the diversions to the Delta from the Sacramento and San Joaquin Valleys and diversions from the southern Delta such as those for the federal Central Valley Project and the State Water Project.

To serve both the State Water Project and the federal Central Valley Project, an interagency committee has proposed the Peripheral Canal and the Department has adopted it as the Delta facility of the State Water Project. The Department of Water Resources is studying the timing of construction, the physical works, the operation, the size, and the exact location of the Peripheral Canal.

Through releases along the canal route, the Peripheral Canal will secure the water supply needs of the interior Delta and will protect fish and wildlife from massive artificial cross-channel flows. Through coordinated releases and river flows, the intrusion of salt water will be limited to a specified relatively small area of the western Delta—thereby protecting the in-channel water supply for about 90 percent of the rich agricultural land within the Delta. An overland substitute water supply will be made available within the extreme western Delta, the portion affected by salinity intrusion.

North Coastal Area

Water in the North Coastal area is a promising source of supplemental supply to help meet statewide needs in the years beyond 1990. The Department has begun extensive analysis of water quality problems throughout the North Coastal area. It maintains 40 stations for measurement of turbidity, 20 for measurement of temperature, 34 for measurement of sediment, and 20 for determination of general water quality.



MIDDLE FORK EEL RIVER DEVELOPMENT will begin at Dos Rios reservoir. Project water will be delivered by gravity diversion to Rancheria reservoir and will then be released into the Sacramento River.

Having recently completed investigations of possible development of the South Fork Eel, the Trinity, and the Klamath Rivers, the Department currently is studying:

- A master plan for development of the Eel and Mad Rivers.
- Alternative conveyance systems for transporting water from the North Coastal area to the Sacramento-San Joaquin Delta.
- Major multiple-purpose projects which will follow development of the Upper Eel River—projects which would develop recreation and improve local fisheries as well as supply needed water.

Middle Fork Eel River

Developments along the Middle Fork Eel River are being considered as the first North Coastal developments of the State Water Project. The Department seeks a plan which will represent the best development in terms of operational effectiveness, economic efficiency, financial soundness, and social needs.

Like most other major planning programs, the Middle Fork Eel program includes detailed studies in hydrology, geology, design, fish and wildlife, flood control, recreation, water quality, and watershed management. Geologic studies, for example, include the exploratory drilling operations which will provide a sound basis for design. A 4,670-foot core hole along the route of the proposed Dos Rios-Grindstone Tunnel was completed by the Department in September 1966. To help evaluate potential earthquake hazards, the Department has installed three strong-motion seismographs and one special sensitive seismograph at sites on the Middle Fork Eel River and in the area of the proposed Glenn Reservoir Complex.

Depending on the outcome of these studies and on action by the Congress of the United States, construction of the Middle Fork Eel River development would begin around 1975. The development would supply additional water to the State Water Project in the late 1980's. Dos Rios reservoir, in conjunction with levees near the mouth of the Eel River, would provide some flood control for the Eel River Basin.

The Department of Water Resources and the U. S. Corps of Engineers have agreed to develop the Middle Fork Eel River jointly. Under this agreement, the Corps would construct, operate, and maintain Dos Rios reservoir, and the Department would build the conveyance system, probably Dos Rios-Grindstone Tunnel, to deliver water into the Sacramento Valley. The two agencies will carefully coordinate planning, design, construction, and management of all interrelated portions of the project. Public hearings will be held before the size of the dam and reservoir is finally determined.

Ground Water Planning

Local water district managers should be able to predict how their various operations will affect ground water levels. To aid them, geologists and hydrologists of the Department of Water Resources postulated single aquifers to represent major aquifers of particular ground water basins. Each postulated aquifer attempts to duplicate, in composite form, the geologic structure, size, storage capacity, and rate of flow of the individual aquifers in a ground water basin.

Department of Water Resources engineers then created equations to simulate water storage and flow in the composite aquifer. Computers provided solutions to these equations. The solutions described ground water level elevations under a given set of conditions at a given time. Tests have proved the reliability of the method: Using data duplicating hydrologic conditions on a given date, the computers have accurately predicted actual ground water levels for that date.

With such improved knowledge of the effect of their varied operations upon ground water levels, local water district managers can better plan for the use of supplemental water from reservoirs and aqueducts.

Cooperative Agreements

The Department and local water development agencies recently have reached several important agreements to acquire technical data on ground water basins and to analyze various alternative plans for their development in conjunction with other sources of water.

The first of these local-state agreements including substantial local participation were made during the 1966–67 fiscal year. They were for studies of the ground water resources of the Bunker Hill-San Timoteo area, near San Bernardino, and of the Chino-Riverside area.

Late in 1967, several matching-funds agreements were made. These are for studies in which equal contributions are made by the State and by the local agency. Contributions by the local agencies include the services of local-agency personnel to work on the study.

Three of these agreements are for the first year of longer-range studies, with half the cost to be contributed by the local agency and half by the State. They are ground water investigations in Kern County, the Raymond Basin, and San Luis Obispo County.

New Technology

These ground water basin planning studies would not have been possible five years ago. Only in the last five years have mathematical computer models been developed that can predict ground water movement and levels on the basis of the possible future activities of man. Models will soon be developed that can predict not only future quantities of ground water but also ground water quality resulting from man's future activities.

Lower San Joaquin River Water Quality Investigation

The water of the lower reaches of the San Joaquin River has been deteriorating in quality for many years. Irrigation water from the river during recent dry years has been of such poor quality that it has damaged crops when used for irrigation. Scheduled additional water development projects on the San Joaquin River system could further impair the water quality in the downstream reaches of the San Joaquin.

The purposes of this investigation are to determine present water quality and the probable effects on water quality of future water development projects in the area and to plan corrective measures for expected deterioration of water quality in the lower San Joaquin River.

Waste Water Reclamation Projects

Large quantities of water in Califorina pass through only a single cycle of use before they are disposed of to the ocean or other saline water bodies. Some used water is reclaimed to supplement the limited water supply. As urban and industrial water use increases, more and more relatively high-quality sewage and industrial waste water becomes available for reclamation and reuse. This becomes a significant possible new source of water supply. Studies indicate the possibility of reclaiming waste water for use in various areas of Southern California. Results of the studies are used to provide information for legislators and state and local agencies and to encourage the reclamation of waste water of suitable quality.

Regional Planning

The growing water requirements of people, industry, and agriculture are bringing to the attention of the western states the need for coordinated development of the water resources of the entire western region. To promote cooperative planning, California and 10 other western states have formed the Western States Water Council. Aims of the council are to protect and further state and local interests in water development and to continually review all large-scale interstate and interbasin plans for development, control, and use of water resources.

State Water Project COST REPAYMENT

Capital costs of the State Water Project will exceed \$2,800,000,000. Project customers will repay those amounts allocated to water supply, to hydroelectric power generated in Edward Hyatt and Thermalito Powerplants, and to agricultural waste water disposal in the San Joaquin Valley. Local agencies will repay loans from the State for construction of local projects under the Davis-Grunsky Act. Project customers will repay about 90 percent of the total project costs.

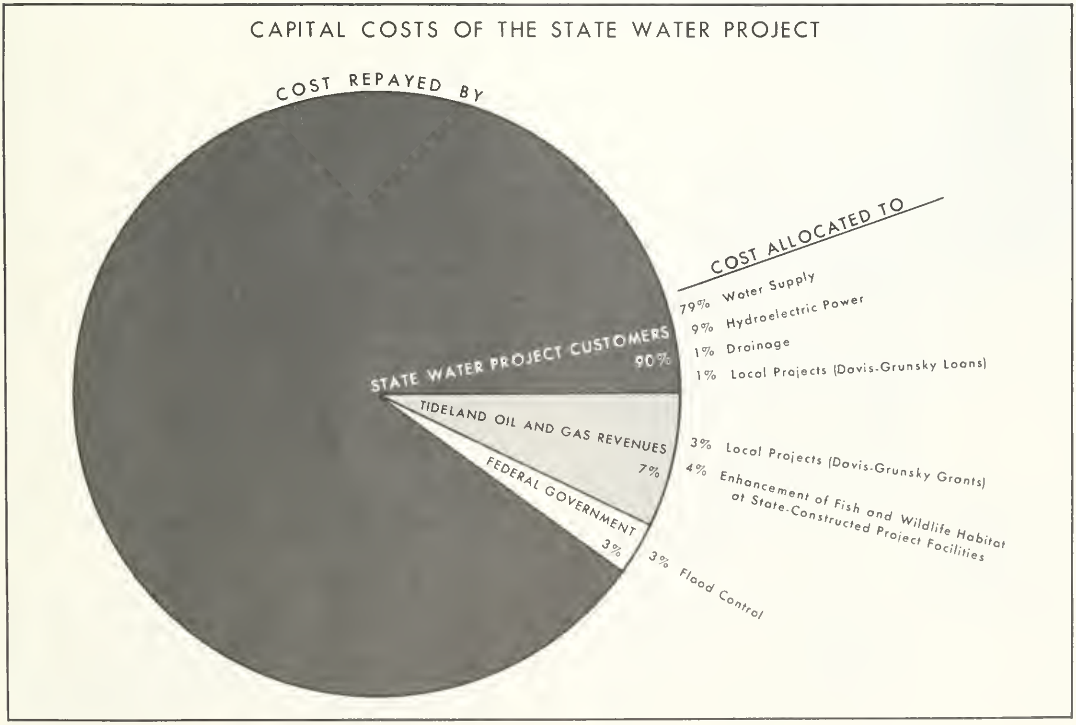
The Federal Government will pay another 3 percent of project costs—those allocated to flood control.

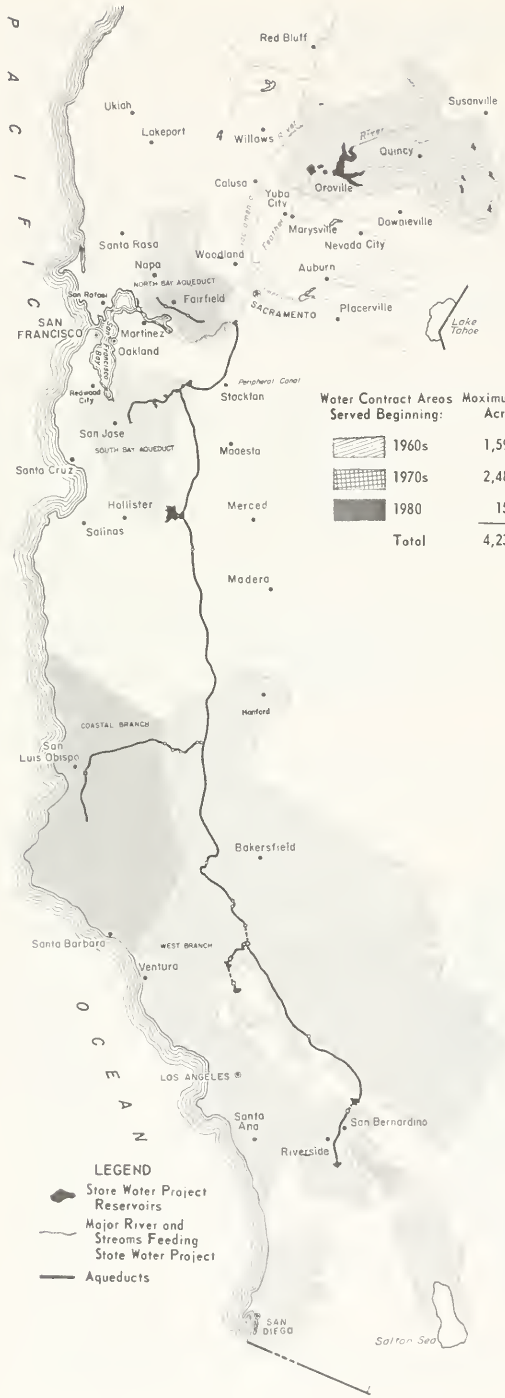
The remaining 7 percent of the capital costs will be paid by the State's tideland oil and gas revenues in the interests of both recreation and enhancement of fish and wildlife habitat. The amount includes repayment of costs allocated to these purposes at state-constructed project facilities and the cost of financing grants for construction of local projects under the Davis-Grunsky Act.

The Customer

California customers will buy water and hydroelectric power from the State Water Project. They will contract for the use of the proposed San Joaquin Master Drain to remove excessively saline agricultural waste waters from the endangered farm lands of the San Joaquin Valley.

Water Customers. Customers for water from the State Water Project are California water agencies clustered in the several areas depicted on the map on the following page. Fulfillment of present contracts will meet





the water needs of Californians until 1990, when the aqueducts of the project will deliver more than 4 million acre-feet annually to users.

Most of the agencies already have begun their annual payments. This money, more than $22,000,000 of which had been collected by the State as of July 1967, repays the costs of State Water Project dams and aqueducts and the costs of delivering water through those aqueducts.

Two thirds of the annual cost of delivering water to the water customers is the cost of power required to pump that water through the aqueducts and across the Tehachapi mountains. In the interests of the water customer, that power must be acquired with the least expense possible.

A basic source of power will be the more than 3 billion kilowatt-hours that eventually will be generated annually by the powerplants on the southerly portions of the California Aqueduct: the San Luis, Devil Canyon, Pyramid, Cottonwood, San Luis Obispo, and Castaic Powerplants. Under a rather complex agreement, the State Water Project and the City of Los Angeles will share the savings to be realized by joint construction of Castaic Powerplant.

Another source of power lies to the Pacific Northwest. In September 1967, the State contracted to purchase surplus power from the Bonneville Power Administration; in October, it contracted to purchase up to 300,000 kilowatts from Seattle, Tacoma, and the Puget Sound Power and Light Company—power originating in Canada. Transmission of this power for California Aqueduct pumping plants over the Extra High Voltage Pacific Northwest-Pacific Southwest Intertie was earlier assured (August 1967) by contract with Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric.

California Aqueduct pumps will require still more power. A third source is the Central Valley Project of the U. S. Bureau of Reclamation; the Department of Water Resources wishes to renegotiate an already executed contract for power from Shasta, Keswick, Trinity, and Folsom Powerplants.

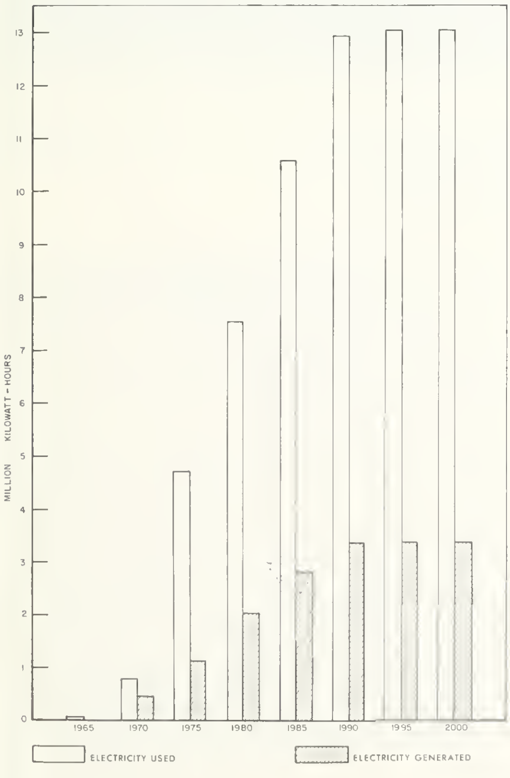
A final source of power, under an agreement signed in November 1966, will supply all supplemental energy required by California Aqueduct pumping plants. The power is to come from four California utilities: Pacific Gas and Electric, Southern California Edison, San Diego

Gas and Electric, and the Los Angeles Department of Water and Power. Under terms of the contract, the State may obtain additional supplemental power for project use from other sources only by giving written notice five years in advance.

Power Customers. The State sells rather than uses the power developed at Hyatt and Thermalito Powerplants. Sale of the power will repay revenue bonds, the proceeds of which will be used to pay for construction of the Oroville and Thermalito power facilities.

Customers for hydroelectricity from the State Water Project are the Pacific Gas and Electric Company, the Southern California Edison Company, and the San Diego Gas and Electric Company. Under a 50-year-minimum contract signed in November 1967, these companies agreed to pay California at least $16,150,000 annually for the almost two billion kilowatt-hour output of Oroville and Thermalito Powerplants when the plants begin full operation early in 1969.

ELECTRICITY USED AND GENERATED IN OPERATING THE NORTH BAY, SOUTH BAY, AND CALIFORNIA AQUEDUCTS



Waste Water Disposal Customers. Although the San Joaquin Valley now contains half the irrigated land in California, growing concentrations of mineral compounds seriously threaten future farm production. Increasingly, these compounds find their way into the soil from agricultural waste waters. As late as January 1967, the California Department of Water Resources and the United States Bureau of Reclamation still planned joint construction of a master drain to remove concentrated waste waters from the valley. Such joint construction would have permitted the State to build and operate a drain large enough to serve endangered areas in the entire valley and the Federal Government to pay its share of costs for waste water discharge from its San Luis service area. An approved contract awaited state and federal signatures when 28 San Joaquin Valley agencies—potential customers of the drain—reported themselves neither willing nor able at that time to repay State Water Project costs allocated to agricultural waste water disposal. The Director of Water Resources had notified these agencies that full repayment would approximate $16 to $20 per acre-foot of waste discharge.

The Department withdrew from the joint project; the Bureau proceeded with plans for a smaller drain.

State Water Project costs remain allocated to agricultural waste water disposal in the San Joaquin Valley, however, and the Department plans eventual drainage construction.

The Federal Government

Oroville Dam will protect Marysville, Oroville, Yuba City, and surrounding towns and farmlands from Feather River flood waters such as those which in 1955 destroyed an estimated $30,000,000 in downstream property. Del Valle Dam will protect the coastal plain of Alameda County from Alameda Creek flood waters such as those which in 1955 and 1958 together destroyed an estimated $5,270,000 in property. The Federal Government, as part of its flood control program, will pay State Water Project costs allocated to flood control by these two dams ($70,000,000 in capital costs).

Tideland Oil and Gas Revenues

In its Davis-Dolwig Act, the California Legislature stated that fish and wildlife habitat associated with the State Water Project must be preserved for the public good. The legislature further declared that facilities for the storage or regulation of water must be so constructed that their potential for enhancement of fish and wildlife habitat and for recreation can be fully realized.

Fulfillment of these purposes benefits not only customers of the State Water Project; it benefits all Cali-

ONE SOURCE OF POWER stilled forever is the Big Bend Powerplant of the Pacific Gas and Electric Company. The waters of Lake Oroville began to rise around the walls of the powerhouse in January 1968 and now inundate the building. In 1966, the State paid $25 million for Big Bend, 5,770 acres of land adjoining, and a 230- to 110-kilovolt connection.

fornians. For this reason, the Legislature added that such construction costs (3.8 percent of the total multiple-purpose capital costs of the State Water Project) should not enter into computation of charges for project water and power.

Capital costs allocated to recreation and to enhancement of fish and wildlife habitat at State-constructed facilities are paid initially from project funds, but these funds are reimbursed at the rate of $5,000,000 annually from oil and gas royalties and bonuses under tideland leases.

As part of its Davis-Grunsky Act, the California Legislature authorized the Department of Water Resources to make grants available for fishery, wildlife, and recreation features of new water supplies developed by local agencies. These grants are financed by project funds derived from tideland oil and gas royalties and bonuses.

The agencies may receive up to half the costs allocated to such features, provided that the amount granted not exceed three fourths of their total construction costs. A grant of more than $400,000 requires specific legislative authorization. Additional money, in limited amounts, may be granted for drinking fountains and rest rooms at initial picnic and camp areas at each reservoir constructed.

At the same time, the Legislature authorized the Department to make state loans of up to $4,000,000 each for the development of new water supplies by local agencies. Such developments must be for domestic, municipal, agricultural, industrial, or recreational uses or for the enhancement of fish and wildlife habitat. For both grants and loans, the proposed water project must conform to the California Water Plan.

The Burns-Porter Act set aside $130,000,000 for Davis-Grunsky grants and loans. An additional $1,423,000 has been expended prior to passage of the act. These monies are considered costs of the State Water Project.

RECREATION

The hundreds of natural and man-made lakes in California each year lure millions of visitors.

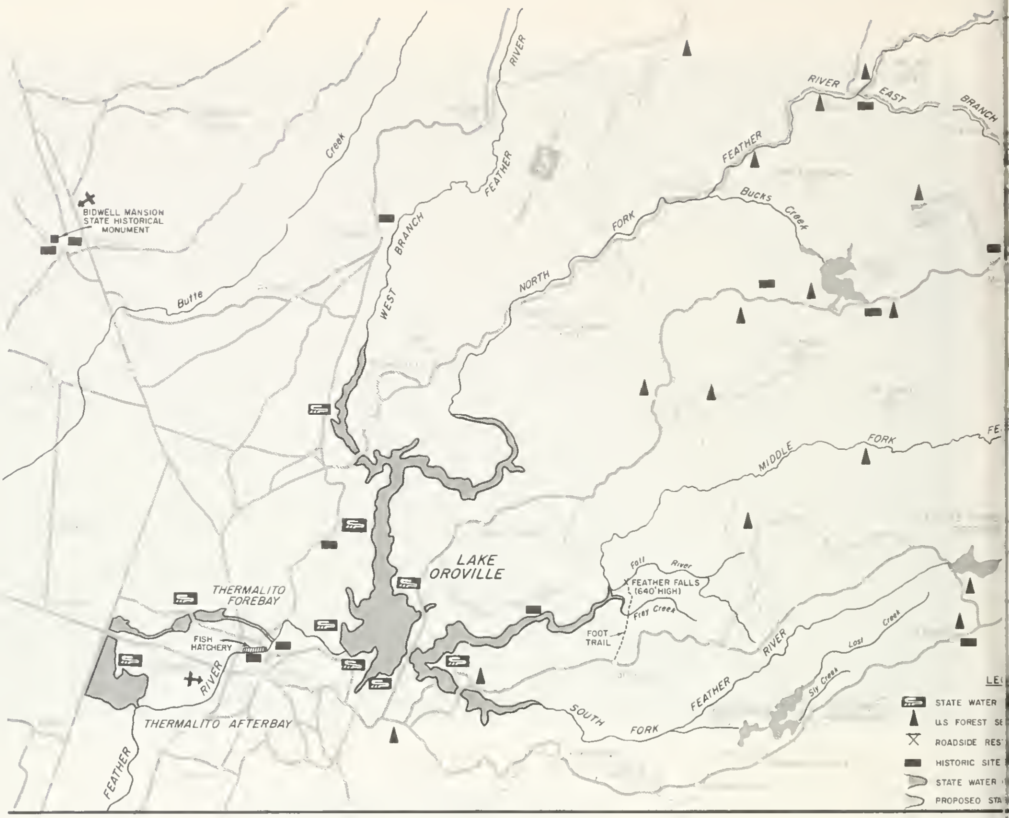
Recreation use of California's lakes is expanding even faster than her population. The number of pleasure boats in the State jumped from less than 100,000 in 1955 to more than 400,000 in 1967. Water skiing rivals snow skiing. Sun, water, beach, and lakeside campground have become part of a summertime way of life.

Recreation and enhancement of fish and wildlife habitat are an integral part of the State Water Project. In addition, the Project, under the Davis-Grunsky Act, assists local agencies throughout the State in developing water resources. The Davis-Grunsky Act provides for state loans to public agencies for local water projects and authorizes state grants and loans for development of the recreation and fish and wildlife potentials of local water projects. Thirteen loans totaling nearly $4 million and twenty grants totaling more than $30 million have been approved under the Davis-Grunsky Act.

The reservoirs of the State Water Project will provide recreation opportunities for millions of Californians. Their distances from centers of population range from a few thousand yards to hundreds of miles. They are located throughout the length and breadth of California and from near sea level to more than a mile above.

Recreation is the principal purpose of several State Water Project reservoirs in the western portion of the upper Feather River Basin. The area's climate and its quiet grandeur invite the vacationing refugee from the noise and hustle of his city life.

Most summer afternoons are sunny and warm; midday temperatures rise into the 80's. Nights are cool, and the clear, black sky shows the camper thousands of stars he could never see from the coastlands or central valleys. The humidity is very low. Only occasionally does a summer shower dampen the forested mountain slopes and the grass-covered meadows and valley floors.



Most precipitation falls in the winter; much is snow at the higher elevations. During the winter and spring, runoff from rainfall and melting snow fills the Feather River tributaries and races westward to Lake Oroville.

Part of the runoff is caught behind the upper Feather River dams. Three of these dams are already constructed; two remain to be built. The water surfaces of each of the reservoirs will be more than 5,000 feet above sea level. All will be within Plumas National Forest.

The Department of Water Resources builds the dams and reservoirs. Recreation facilities are constructed by the Department of Parks and Recreation and operated by both Parks and Recreation and the U. S. Forest Service. Water and sanitary facilities will be provided at all recreation areas.

The first of the five dams, Frenchman Dam on Little Last Chance Creek, was completed late in 1961. Frenchman Lake has a surface area of more than 1,500 acres and a shoreline of 21 miles. Rainbow trout—some of the 300,000 to 400,000 fingerlings planted yearly by the Department of Fish and Game—flash beneath its surface. Frenchman Lake, in addition to supporting recreation, supplies the Last Chance Creek Water District in Sierra Valley.

Antelope Valley Dam, on Indian Creek, was completed late in 1963. Smaller than Frenchman Lake, Antelope Lake has a surface area of about 900 acres and a shoreline of 15 miles. A forest of fir and pine extends to the water's edge. The lake is used solely for recreation. The area has 156 campsites and a boat-launching ramp with parking for 45 cars and trailers. The Department of Fish and Game planted about 300,000 rainbow trout in 1965, a like number in 1966, and more than 140,000 in 1967. Water is released from the lake so as to enhance the downstream trout fishery.

Lake Davis, on Big Grizzly Creek, rises behind Grizzly Valley Dam, completed in November 1966. The lake has a surface area of 4,000 acres and a tree-lined shore of 32 miles. All recreation facilities will be completed in 1968. Lake trout fishing should be excellent. The downstream trout fishery will be enhanced by releases from the lake. Although constructed to provide recre-

ation, Lake Davis also will supply domestic water to Portola and nearby areas.

Two more reservoirs will complete the presently planned water recreation facilities in the upper Feather River Basin. Both will be used entirely for recreation and enhancement of fish and wildlife habitat. The first of these two will be Abbey Bridge reservoir. Located on Red Clover Creek, the reservoir will have 1,900 acres of water surface, 21 miles of shoreline, 125 campsites, 10 boat access campsites, 35 picnic units, and a boat-launching ramp with parking for 170 cars and trailers. Vacationers may expect excellent trout fishing. The second reservoir, Dixie Refuge on Last Chance Creek, probably will have more than 800 acres of mountain-ringed water surface and 10 miles of shoreline.

To the west, downstream, and at the eastern edge of the great Central Valley, the State Water Project will make available for recreation 20,600 acres of water surface and 10,200 acres of land in the Oroville area. Here, the waters of the three forks of the Feather River converge to form Lake Oroville. This lake, with its 167 miles of shoreline, will provide recreation opportunities for millions of Californians.

The two other reservoirs of the Oroville area will also provide recreation use—Thermalito Forebay, with 10 miles of shoreline, and Thermalito Afterbay, with 26 miles of shoreline. In addition, the 5,800-acre borrow area, where material was removed for use in the dam embankment, will be developed for fish and wildlife use and for recreation.

The regulated release of water from Lake Oroville will flow down the Feather and Sacramento Rivers and into the Sacramento-San Joaquin Delta, which supplies water for the North Bay Aqueduct, the South Bay Aqueduct, the California Aqueduct, local water distribution systems, and the Delta-Mendota Canal. The Sacramento-San Joaquin Delta is one of the most popular recreation areas of California. Thousands of sportsmen traverse the maze of waterways in boats or cast their fishing lines from the hundreds of miles of shoreline. Waterskiers split the smooth water in the shadows of trees and shrubs along the banks.

At the edge of the metropolitan San Francisco Bay area, visitors will be counted in the millions within the recreation areas of Lake Del Valle, five miles south of Livermore. The first recreation facilities should be ready for the 1969 season. The lake will regulate the flow of water through the South Bay Aqueduct. During the winter, it will provide flood control.

Lake Del Valle will cover a long, narrow area near the northern end of Arroyo Del Valle. Gently rolling lands to the northeast become steeply rolling in the southwest. Annual grasses and perennials cover the hilltops and southern slopes. Along the bottom of the arroyo and the lower slopes grow live oak, blue oak, sycamore, bay, and digger pine trees, and scattered buckeye ceanothus, and elderberry.

Sixty-four miles south of the Delta Pumping Plant and along the aqueduct, hundreds of thousands of visitors each year will enjoy the recreation facilities of San Luis reservoir and O'Neill Forebay. The reservoir will store and regulate water pumped from the Sacramento-San Joaquin Delta for use in the San Joaquin Valley and Southern California. The dams for the reservoir and forebay are built, and some immediate public-use recreation facilities have been installed at O'Neill Forebay. By the year 2020, the annual recreation use of the area is expected to be more than four million visitor-days.

The State Water Project will bring new outdoor recreation opportunities to millions of Southern Californians. The people of the great metropolitan area will be offered, close to home, opportunities for swimming, fishing, boating, water skiing, picnicking, and hiking. Four reservoirs that eventually will accommodate an annual recreation use of more than 10 million visitor-days are Lake Perris and Pyramid, Castaic, and Silverwood Lakes.

Pyramid Lake will lie in a spectacular rock setting, visible from Interstate Route 5 just south of the Tehachapi Mountains. When completed in 1972, it will have a 1,200-acre water surface and a 21-mile shoreline.

Castaic Lake, about 40 miles north of downtown Los Angeles and near Interstate Route 5, will be ready for use in 1971. The lake will have a water surface of 2,600 acres and a shoreline of 34 miles.

Silverwood Lake will be built on the west fork of the Mojave River, about 10 miles north of San Bernardino. The 1,000-acre lake is to have a shoreline of 13 miles. Recreation facilities are to include 600 camping units in addition to swimming, picnicking, and boat launching areas.

Lake Perris, the southern terminus of the State Water Project, is currently scheduled to be in operation in 1973. It will have a water surface of 2,000 acres and a shoreline of 16 miles. Surrounding the lake will be nearly 1,500 acres of recreation land.

Plans also are being made for fish and wildlife sites along the California Aqueduct.

Design

Loping beside the rolling hills of the western Central Valley, leaping the Tehachapis, and plunging down, down to the urban centers of Southern California, the California Aqueduct will travel twice further than any natural river in the State. Along its northern length, it will carry nearly as much water each year as the once-rampaging Feather River can pour into Lake Oroville. To rein in the waters of the State, to bridle smoothly southward what once rode wildly westward, engineers of the Department of Water Resources, with extensive help from private consultation firms and individuals, undertook one of the great design efforts of the century.

How would they control flow along hundreds of miles of open aqueduct? How would they push so much water over the 2,000-foot Tehachapi mountains? How would they protect the aqueduct from the shifting forces of the great earthquake faults it had to cross?

Where the aqueduct winds along the western edge of the San Joaquin Valley, the channel had to be designed to allow rapid changes in rate of flow with little change in water level. Fluctuation of the level more than a few inches could damage the concrete walls and the lining of the channel, necessitating expensive repairs and delaying water deliveries.

Where the water has to go up a mountain side, pumps had to be designed to lift 4,100 cubic feet of water a second through two conduits 8,500 feet long to a height nearly 2,000 feet above the pumping plant.

Where the aqueduct crosses the seismatically active Tehachapi mountain range, it had to be designed so that an earthquake or slow fault movement would cause as little damage as possible to pumping plants, pipelines, and tunnels.

Aqueduct Design

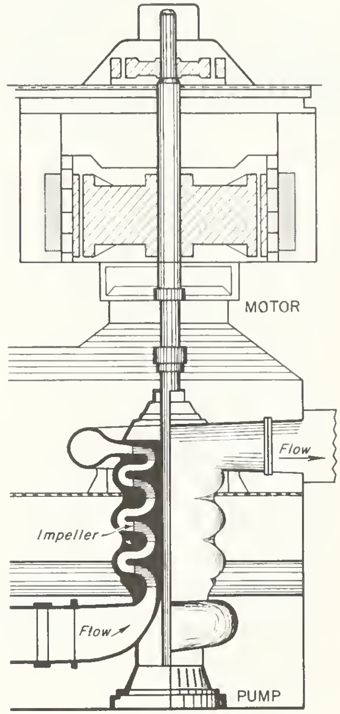
The California Aqueduct is designed to operate like a 444-mile-long water pipe, with numerous smaller pipes at irregular intervals to release water at irregular times. This immense water pipe will include four reservoirs, a forebay, an afterbay, six pumping plants, two powerplants, and four tunnels.

Some 380 miles of the aqueduct will be open channel, each section of which must be kept at a nearly constant level regardless of sudden demands for more or less water from various outlets along the aqueduct.

To keep the water level nearly constant, a system had to be designed to provide the necessary monitoring and control. For this system, mechanical, electrical, and electronic equipment had to be designed — mechanical check gates and the machinery to move them, electric motors to operate the mechanical equipment, and automatic electronic control devices to ensure that the electrical and mechanical equipment operates in precisely the proper way at precisely the proper time.

Pump Design

Even as they designed the California Aqueduct, engineers of the Department of Water Resources knew they would have to accomplish what never before had been attempted. For the Tehachapi mountain crossing, pumps had to be designed to lift 7,670 tons of water a minute, 2,000 feet high, day in and day out, through



CENTRIFUGAL PUMP is one of 14 that will lift water across the Tehachapi Mountains. Driven by an 80,000 horsepower motor, the four pump impellers will spin at 600 rpm.

The first impeller (bottom) will draw water from 77 feet below the aqueduct surface. The centrifugal force of the outwardly thrown water will increase the pressure of the water entering the second impeller. Each impeller, in turn, will increase the water pressure until, after the fourth stage, the pressure will be great enough to lift a column of water 2,000 feet and into Tehachapi Afterbay at the south end of the Carley V. Porter Tunnel.

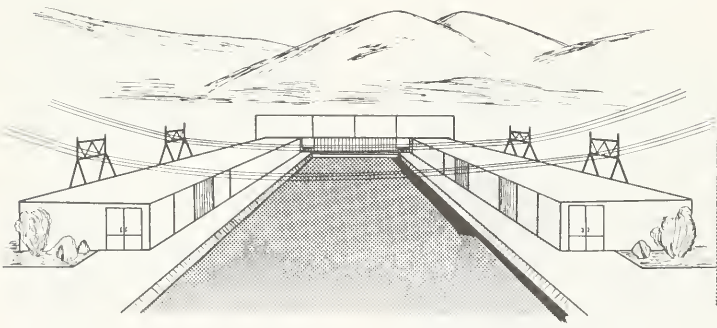
The typical pump will be about 31 feet high and 16 feet in diameter.

spring, summer, fall, and winter, year after year. No one had yet produced pumps capable of pushing such an enormous quantity of water over so high a barrier for so long a sustained time. Yet, the State Water Project was predicated largely on confidence that such pumps could be manufactured. DWR engineers knew that pumps in Europe had been lifting smaller quantities of water to greater heights for some years.

The first problem to be solved was whether to pump water to such a height in a single lift or whether to pump it in two or even three lifts. The consulting firm of Daniel, Mann, Johnson, and Mendenhall was engaged to help answer this question.

One, Two, or Three?

In the summer of 1964, a team of engineers visited more than 30 plants in Europe and a dozen in the United States to study high-lift pumps. Three pump manufacturers, one in Swtizerland, one in Germany, and one in the United States, were engaged to study designs and models of the types of pumps that would be used for each of the three systems—the single-lift, two-lift, and three-lift systems. The single-lift system would require four-stage pumps; the two-lift system would require two-stage pumps; the three-lift system could use single-stage pumps.

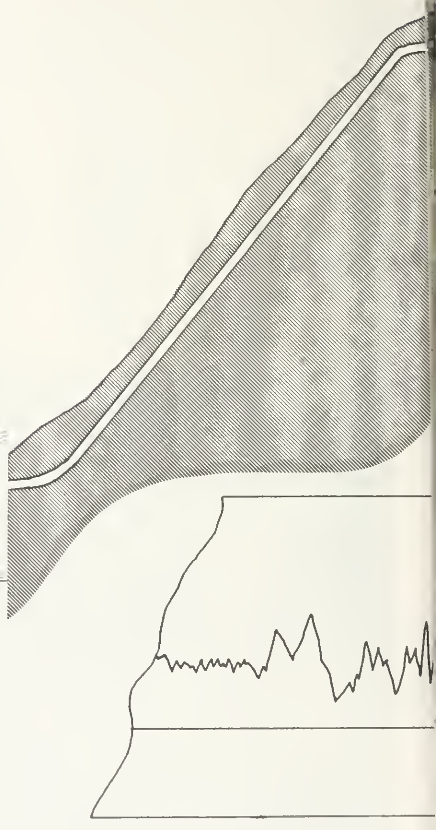


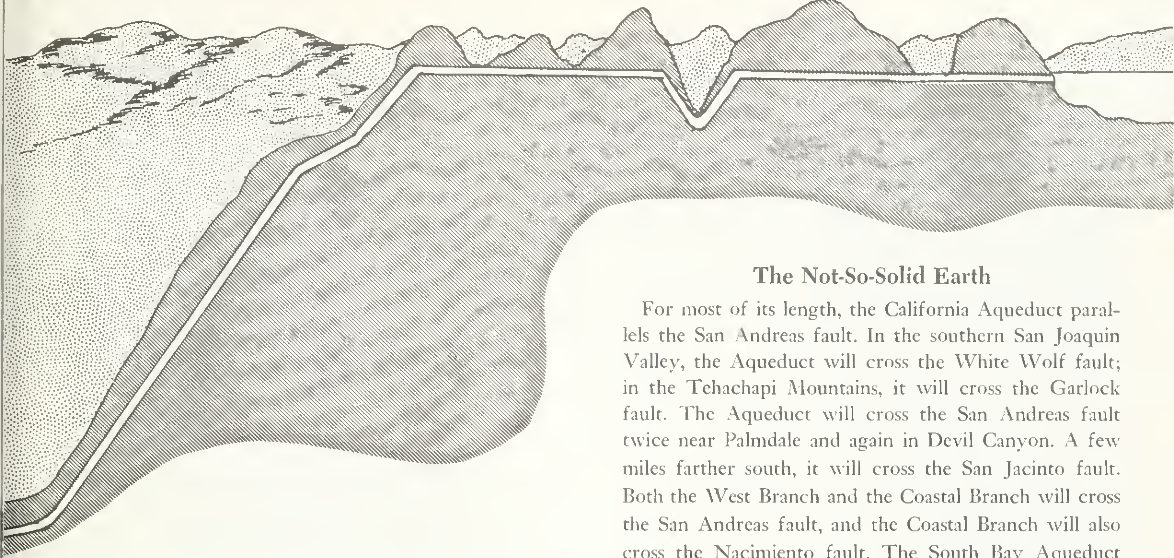
After its engineers had considered pump design, model tests, economic data, and local geology, the Department of Water Resources announced in August 1965, that a single-lift pumping system would be more reliable than the two-lift or three-lift systems. The Department's consultants agreed with this decision.

Model Tests

But who would make the pumps? The decision had to be made on the basis of pump efficiency and price. Because of the enormous amount of power that would be used, an increase in efficiency of as little as one tenth of one percent could reduce operating costs by thousands of dollars per year.

Only three companies in the United States proved qualified to manufacture a pump that could lift 7,670 tons of water a minute over a mountain 2,000 feet high. In June 1966, these three companies were engaged to build and test competitive scale models of four-stage pumps of the kind needed for the single-lift Tehachapi Crossing. Each American company turned over the design and manufacture of the model to a European affiliated company that had built pumps used under conditions similar to those at the Tehachapi Crossing. An





The Not-So-Solid Earth

For most of its length, the California Aqueduct parallels the San Andreas fault. In the southern San Joaquin Valley, the Aqueduct will cross the White Wolf fault; in the Tehachapi Mountains, it will cross the Garlock fault. The Aqueduct will cross the San Andreas fault twice near Palmdale and again in Devil Canyon. A few miles farther south, it will cross the San Jacinto fault. Both the West Branch and the Coastal Branch will cross the San Andreas fault, and the Coastal Branch will also cross the Nacimiento fault. The South Bay Aqueduct crosses two very active faults, the Calaveras and the Hayward.

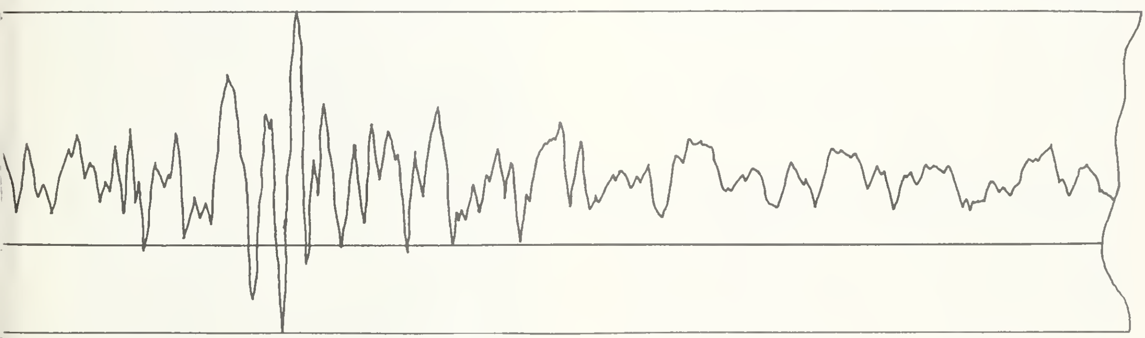
The State Water Project is designed to minimize the effects of probable fault movement—both the sliding that occurs slowly over the years and the sudden slip that makes an earthquake.

An earthquake of the intensity of the 1857 Fort Tejon earthquake might rupture the ground for hundreds of miles along the San Andreas fault and break the California Aqueduct at Devil Canyon and Palmdale, the West Branch at Quail Lake, and the Coastal Branch near Cholame. Such an earthquake could also break both the Los Angeles Aqueduct and the Colorado River Aque-

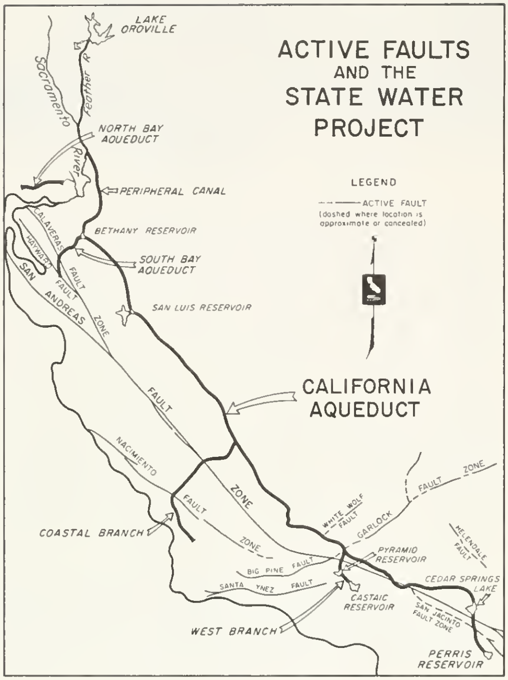
independent laboratory at East Kilbride, Scotland, was selected to further test and evaluate the three models.

On the basis of test results and price quotations from the three manufacturers, contracts have been awarded for the first 11 of the 14 pumps of Edmonston Pumping Plant. Work under these contracts is scheduled for completion in 1972. The rest of the pumps will not be needed until about 1980.

Pump efficiencies will be higher than 92%. The price for the 11 pumps ($18,090,000) will be 14% below the estimate by Department engineers. The price of the motors to power the pumps ($7,630,000) will be 42.5% below the Department estimate.



SEISMOGRAPH TRACINGS enable earth scientists to calculate the direction, force, and duration of seismic movements. The seismograph itself sits on solid bedrock so that its delicately mounted needle can vibrate when the earth does. In practice, the needle often is a beam of light.



duct, severing the entire imported water supply to the metropolitan area of Southern California. Earthquakes, even when the fault is at a considerable distance, could trigger catastrophic landslides, as happened in Alaska in 1964.

The slow movement of crustal blocks could just as surely disrupt or damage project facilities. A small annual creep—the maximum documented in recent years has been 3 or 4 centimeters—would add up to a significant movement during several decades. Continued gradual movement would eventually offset sections of everything that straddled the fault.

In the State Water Project, every design decision—every alternative for a dam or pump location or a conveyance route—is influenced by the possibilities of future fault movement. Project facilities are designed to minimize these dangers. Dams and reservoirs are designed to avoid catastrophic damage from major earthquakes and fault movements. Canals, tunnels, and pipelines are designed so they will not be severely damaged by slow fault movement and shaking by major quakes. For example, pipe joints in the South Bay Aqueduct where it crosses the Hayward fault are made of rubber so the conduit will move with the fault instead of cracking. Conduits cross known currently active faults at the surface rather than in tunnels, a design procedure that will facilitate quick repair if the aqueduct is ruptured or blocked by a major quake.

Where the West Branch of the California Aqueduct crosses the San Andreas fault, about 3 miles south of the Kern-Los Angeles County line, Quail Lake will form the connecting link between aqueduct segments to the north and to the south of the very active fault. If fault movement shifts the relative positions of the two segments, it probably will not interrupt the flow of water through the aqueduct.

Watershed to User

The water flows on, from the snowy peaks of the Feather River to the neat frame house in the arid south. Little Johnny Jones turns a water tap and the water runs free. It is a routine thing he may do dozens of times a day. Little does he care about the decades of planning and of political action, and the thousands of man-years of design and construction required to put the water into a drinking fountain. And this, perhaps, is the real tribute to the planner, the designer, and the builder of a great water project.

THE BIG DAM is built. The last loads of earth topped out the embankment in October, 1967. Oroville Dam, the highest earthfill dam in the western world, rises 770 feet from its base, extends nearly 7,000 feet between abutments, and contains 80 million cubic yards of material. Behind Oroville Dam rises Lake Oroville, 3.5 million acre-feet with a surface area of 15,500 acres. In January 1968, two months after the closing of diversion tunnels, Lake Oroville looked like this. When the lake fills, its waters will rise to the top of the tree-cleared area, the broad, light-colored band here showing above the water level.

CONSTRUCTION . . . . State Water Project Milestones

Major State Water Project facilities essentially completed in the Oroville area are Oroville Dam and Thermalito Powerplant, Diversion Dam, Power Canal, Forebay, and Afterbay. The first units of Hyatt Powerplant are installed; the last of the remaining units are to be installed by the spring of 1969. Hyatt and Thermalito Powerplants will have a combined dependable capacity of 725,000 kilowatts.

Three State Water Project reservoirs in the Upper Feather area have been completed: Frenchman Lake, Antelope Lake, and Lake Davis.

The focus of construction has now shifted southward.

Water now flows the length of the South Bay Aqueduct. Lake Del Valle, to be used to regulate South Bay Aqueduct flow and to provide flood control and recreation benefits, is essentially completed.

The first four units of the Delta Pumping Plant are installed. All eleven units eventually will have a pumping capacity of 3,800,000 gallons per minute.

The northern 65 miles of the California Aqueduct have been constructed. Water from the Delta is flowing into O'Neill Forebay, which is both a forebay and an afterbay for the San Luis Pumping-Generating Plant.

San Luis Dam was topped out in July 1967 by the U. S. Bureau of Reclamation. The earthfill dam, less than half as high but more than twice as long as Oroville Dam, contains nearly as much material—77 million cubic yards—and has a capacity of more than 2 million acre-feet for regulation of aqueduct flow.

Five units of the San Luis Pumping-Generating Plant are installed. All eight pump-generators are to be installed by September 1968.

The 106-mile length of the California Aqueduct from O'Neill Forebay to Kettlemen City is constructed for water deliveries to Kern and Kings Counties.

About 20 miles south of O'Neill Forebay, all six units of the Dos Amigos Pumping Plant are installed. The pumps will lift the water of the aqueduct 120 feet so it can continue southward by gravity flow.

The first 24 miles of aqueduct south from Kettleman City is nearly completed. The length from there to Buena Vista Pumping Plant is to be constructed by October 1969.

At the southern end of the San Joaquin Valley, three pumping plants are under construction to boost the water of the California Aqueduct 950 feet as it nears the Tehachapi Mountains. These plants—Buena Vista, Wheeler Ridge, and Wind Gap—and 40 miles of aqueduct will be completed in time to deliver water to Edmonston Pumping Plant in 1970.

Work is underway on Edmonston Pumping Plant. The site has been excavated. Construction of the first 11 of the 14 pumps has begun.

The first three Tehachapi Tunnels are nearly completed: Tunnel No. 1, 1½ miles; Tunnel No. 2, ¾ mile; Tunnel No. 3, 1¼ miles. The 5½-mile-long Carley V. Porter Tunnel is under construction. These tunnels, 20 to 23.5 feet in diameter, will carry the entire output of Edmonston Pumping Plant, a maximum of 7,670 tons of water a minute, into Tehachapi Afterbay, for transfer east along the California Aqueduct and south along the West Branch in Los Angeles County.

All Tehachapi feaures, from Edmonston Pumping Plant to the Tehachpai Afterbay, are to be constructed in time for use in 1971.

The 104 miles of aqueduct southwest from Tehachapi Afterbay are to be built in time for water delivery to Silverwood Lake in 1971. Along the way, Pearblossom Pumping Plant will be built to boost the aqueduct water another 545 feet—400 feet higher than the water surface of Tehachapi Afterbay. Cedar Springs Dam, with a crest elevation of 3,380 feet, will form Silverwood Lake, the highest reservoir of the State Water Project south of the Upper Feather area. This dam is to be ready to hold project water in 1971.

THIS 104-mile section of the California Aqueduct was essentially completed in December 1967. The section will carry water from O'Neill Forebay to Kettleman City. Turnouts along the route will divert irrigation water to croplands in Kern and Kings Counties. Deliveries began in January 1968.

The last 35-mile section of the California Aqueduct, from Silverwood Lake to Lake Perris, is also scheduled to be constructed in time to carry water in 1971. This section begins with the four-mile-long San Bernardino Tunnel, on which construction began in 1967. Construction of Devil Canyon Powerplant and of Lake Perris, the terminal facility of the California Aqueduct, is currently scheduled to start in 1969, with completion early in 1973.

The West Branch of the California Aqueduct is scheduled to be built in time to carry water in 1970 from Tehachapi Afterbay to Castaic Lake, 40 miles northwest of Los Angeles. In addition to some 20 miles of canals and pipelines, major structures of the West Branch will be the Oso Pumping Plant, Pyramid and Castaic Dams, and the seven-mile-long Angeles Tunnel, now under construction. Castaic Powerplant is to be constructed and operated by the City of Los Angeles.

The Coastal Branch of the California Aqueduct will extend about 100 miles from the main line of the aqueduct, near the boundary between Kings and Kern Counties, to Santa Maria Terminus, about 25 miles southeast of San Luis Obispo. The first 15 miles of the Coastal Branch, including Las Perillas and Badger Hill Pumping Plants, are to be constructed in time for use in 1968. The rest of the Coastal Branch, including three pumping plants and a powerplant, is to be ready for water deliveries about 1980.

As construction proceeds on the southern portions of the California Aqueduct and as the demand for water from the State Water Project increases in the 1970's, the Peripheral Canal will be needed to convey water from the Sacramento River at the northern end of the Delta, around the eastern edge of the Delta, to Clifton Court Forebay for pumping into the California Aqueduct, the South Bay Aqueduct, and the Delta-Mendota Canal of the federal Central Valley Project. Excavation of the Peripheral Canal will begin in 1971; the canal will be constructed in time for use in 1976 or early in 1977.

Significant economies will result from coordination between construction of the Peripheral Canal and the section of the Westside Freeway (Interstate 5) that will parallel much of the canal. Material excavated to build the canal will be used by the Division of Highways as fill for the freeway. Thus the Department of Water Resources will not have to acquire so much farmland on which to dispose of surplus material, and the contractor for the Division of Highways will not have to obtain as much land from which to obtain fill material.

CALIFORNIA AQUEDUCT swings southeast beneath the new Westside Freeway. In the background rise the Diablo Mountains.

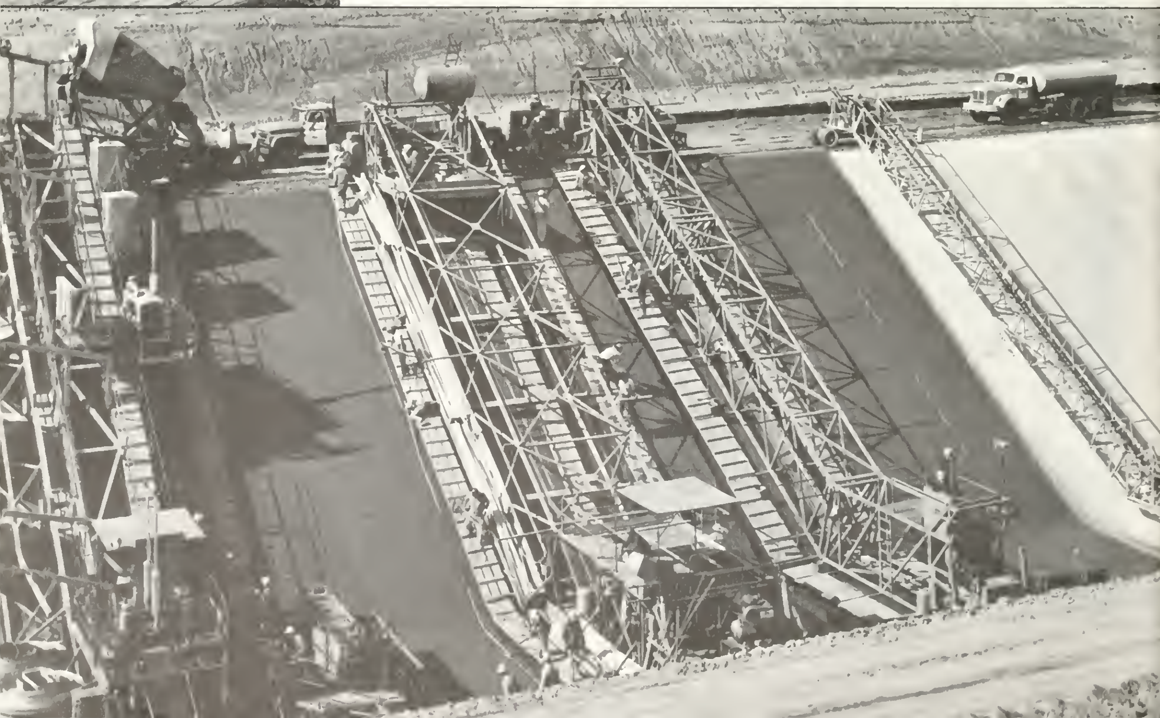
TRIMMER (top) moves along a reach of aqueduct and smooths the slope for paving. Excess material is deposited in a windrow beside the aqueduct. Approaching in the background is the paving train, the series of jumbos (left and bottom) from which the entire paving operation is done.

The concrete is laid from the paving jumbo (bottom left). Waterstop strips are unrolled from huge spools and laid longitudinally into the surface of the concrete. A "guillotine" cuts transverse expansion joints in the concrete.

From a second jumbo (bottom center), plastic strips are placed in the joints. The next day, the strips are removed and the joints are filled with a sealant.

The third jumbo is a platform for finishing the concrete.

From the last jumbo (bottom right), a sealing compound is painted onto the finished concrete to keep the surface from drying before it cures.



Operation

In 1962, shortly after water first flowed through a reach of the South Bay Aqueduct, DWR engineers learned that thousands of clams threatened to make chowder of aqueduct operations. For a very brief moment, the astonished engineers feared they might have licked the problems of planning, design, and construction only to be foiled by the sex life of *Corbicula,* the Asiatic Clam. Corbicula multiplies in the clear waters of the aqueduct Interim Canal and settles thickly along the canal bottom. By simply being there in vast numbers, Corbicula significantly reduces the canal cross section and, thus, its carrying capacity. Attacks upon Corbicula have been varied, persistent, and mostly successful, but the clams remain a problem to be resolved in the operation of the South Bay Aqueduct.

Nor are clams the only aquatic organisms to cause significant operational problems in the aqueduct. Submersed aquatic weeds and attached filamentous algal growths have restricted the carrying capacity by clogging bar screens and restricting water flow.

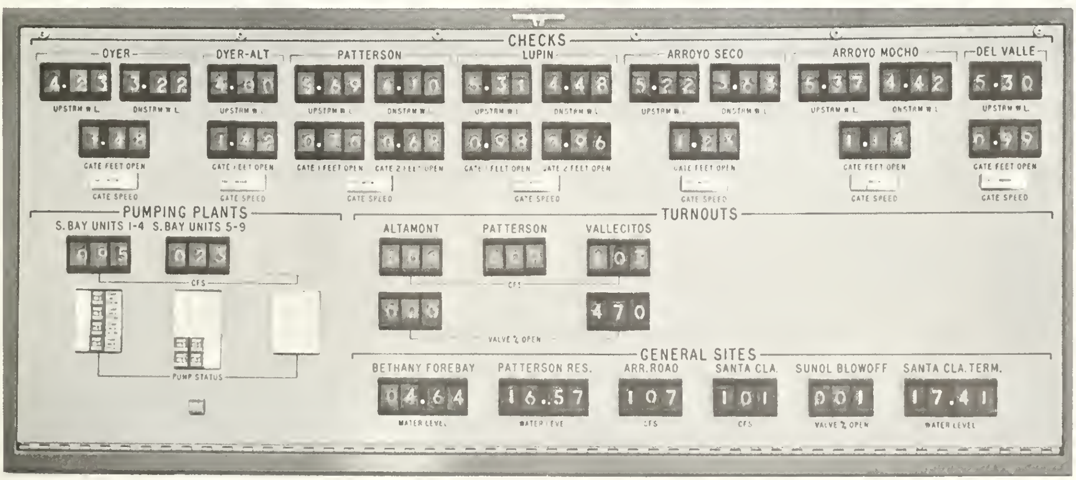
Solutions to such problems are important to the future of the entire State Water Project. The completion of the California and North Bay Aqueducts will introduce additional problems related to aquatic organisms similar to those found in the South Bay Aqueduct. Sacramento-San Joaquin Delta Water, lifted 200 feet above sea level by the Delta Pumping Plant, will increase in clarity as it moves through Bethany Forebay. Photosynthetic aquatic organisms may form and attach themselves to the sides of the project aqueducts to depths as far down as necessary light filters. When the Peripheral Canal begins operation, a further increase in water clarity probably will intensify the problem of excessive population of aquatic organisms in the South Bay Aqueduct and the California Aqueduct.

A more distressing problem, one which actually has hindered operation of the South Bay Aqueduct, has been landslides. Landslides at times have blocked various portions of the Dyer Canal section of the Aqueduct and have interrupted service to water agencies. Geologists and engineers remain convinced that to anticipate such landslides at the time of design would have been impossible.

Earth movement along the South Bay Aqueduct has proved to be a test of the patrol schedule for operation of the aqueduct as well as a test of emergency repair procedures. As each incident occurred, emergency crews rushed to repair the damage. Those corrective measures which proved necessary will be reflected in planning for operation of features of the State Water Project still under construction.

Lesser problems have arisen during the operation of the South Bay Aqueduct. Maintenance men have learned

CONTROL PANEL at the Delta Pumping Plant enables Department personnel to control project water deliveries through the South Bay Aqueduct.



the best means of pulling swimming dogs, frightened deer, sodden sheep, and drowning cows from the aqueduct water. They have learned how to control vandalism and to reduce target shooting on the aqueduct right-of-way. They patrol, clean, and grease equipment; they fire-guard the structures, mow weeds, check gages, and clean culverts.

The South Bay Aqueduct is proving the testing ground for space-age automation of aqueduct control. What Department of Water Resources engineers learn about automation in the South Bay Aqueduct they intend to apply to automation in the far more complex California Aqueduct.

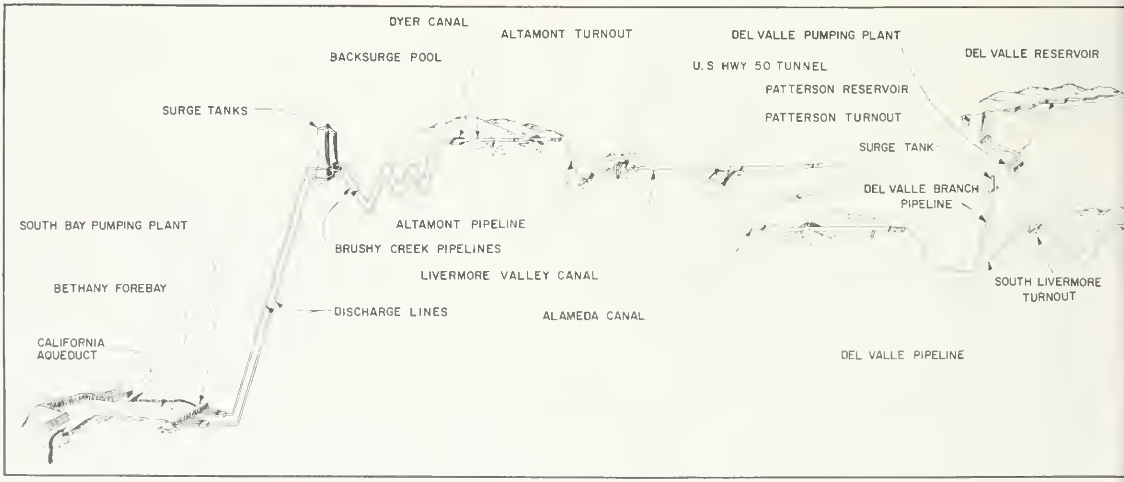
Operation of the South Bay Aqueduct is monitored by computer in the Delta Control Center. This computer ties the South Bay Pumping Plant and the 44-mile South Bay Aqueduct to one control console, making possible the operation of the entire system from a central point. The computer sends coded instructions to equipment in the South Bay Pumping Plant and to individual sites along the aqueduct. The codes are such that only the specific piece of equipment addressed can respond. This method ensures against spurious signals accidentally operating a piece of equipment. The computer scans approximately 100 vital points at the plant and 75 along the aqueduct to alert the operator to abnormal conditions.

As water demands of the system change, the Delta Control Center can start and stop the necessary pumps and can raise or lower the necessary check gates to accommodate change in the rate of flow. A set point controller sensitive to canal water level can maintain the gate settings within one hundredth of a foot. The Control Center can regulate turnouts, as well as check gates, so as to satisfy individual customer needs.

During steady-state flow, the control console monitors the entire system and updates information every two minutes. During flow changes, the console can scan individual check or turnout sites continuously.

The operator can obtain operational information directly from the computer in Sacramento Control Central. Conversely, Sacramento may monitor or assume full control of the South Bay Pumping Plant and the South Bay Aqueduct.

At present the South Bay Aqueduct is operated by computer control, by on-site manual control, and by remote manual control. Such varied operation gives Department of Water Resources engineers an opportunity to compare results of three operational systems while water actually flows through the South Bay Aqueduct. Operational data is being collected, analyzed, and evaluated. This evaluation will assist in developing a control system for the reservoirs and aqueducts of the entire State Water Project.



SOUTH BAY AQUEDUCT begins at the South Bay Pumping Plant, on the shore of Bethany Forebay. From 1962 until late in 1967, water for this aqueduct came from the U. S. Bureau of Reclamation's Delta Mendota Canal, through an interim intake canal to Bethany. The water is now pumped into Bethany Forebay by the Delta Pumping Plant. The giant earthfill Del Valle Dam was topped off early in November 1967—fully three months ahead of schedule. Construction is still in progress on Lake Del Valle and Del Valle pipeline and pumping

The capability of using these various kinds of control in the State Water Project will provide better customer service, will allow less expensive operation of aqueducts and pumping plants, and will provide for immediate response to emergencies.

Flow through the California Aqueduct, with its more than 7,000 acres of open water surface, will be constantly changing to meet the ever-changing demands of the dozens of State Water Project customers. Every change in water delivery, at any point along the aqueduct, will require a change in the rate of flow throughout the length of the aqueduct from the Delta Pumping Plant to the point of delivery.

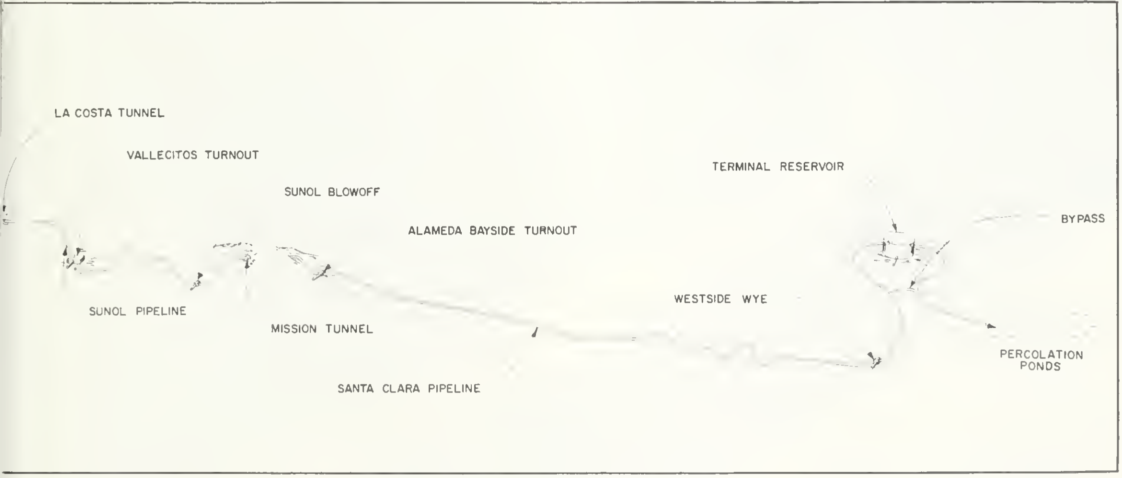
In the conventional method of changing the rate of flow in open channels, the input at the water source (as at the Delta Pumping Plant) is first increased or decreased by starting or stopping one or more of the pumps. Then, as the increased or decreased flow reaches the first downstream check structure, the check gates are raised or lowered to accommodate the change. The sequence continues as the increase or decrease in flow moves downstream. The sequence moves only as fast as a drop of water moves along the channel; as long as 10 days would be required for a change in delivery rate at the southern end of the California Aqueduct. Such slow response to control greatly reduces the flexibility of customer service.

Another shortcoming of conventional aqueduct operation is the higher average cost of pumping. To get water to Castaic Lake and Lake Perris, pumps would have to be operated at various times of the day and week. If the flow from the Delta Pumping Plant were increased at 10 pm Monday, when power costs are relatively low, the increased flow would arrive at Dos Amigos Pumping Plant 85 miles farther downstream about 8 am Wednesday, when power costs are high. The story would be repeated at various pumping plants along the aqueduct, and they would have to be operated with little regard for efficiency with respect to power costs.

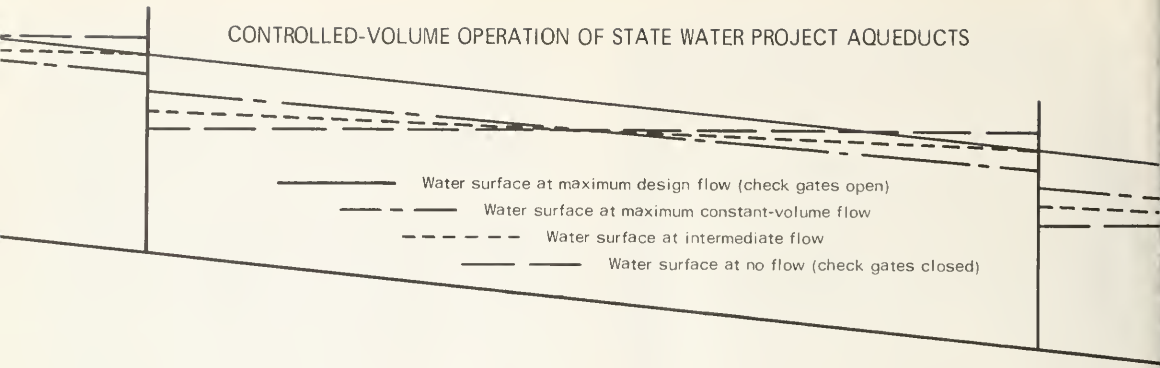
The third deficiency of conventional aqueduct operation is that such an operation method does not provide for immediate response of pumping plants and check gates to emergencies.

The California Aqueduct could be ruptured by earthquake. Unless flow throughout the upstream aqueduct were checked quickly, a rupture could release thousands of acre-feet of water onto areas containing no significant natural drainage channels. To construct wasteways or detention reservoirs to handle such emergency flooding would be excessively costly.

Remote manual or computer control will help resolve all three major problems of conventional operation—lack of flexible customer service, frequent necessity of



plant. The lake will store water for irrigation and for municipal and industrial use, will help to regulate the flow of the South Bay Aqueduct, will help to control flooding in the southern Alameda County area, and will provide recreation opportunities for millions of California residents in years to come. Excess water from the Aqueduct will be spread in percolation ponds, where it will help to replenish the ground water supply.



OPEN-CHANNEL LENGTH OF AQUEDUCT will operate like a series of long, narrow reservoirs, with check gates to release water from each "reservoir" into the next one downstream. The average water level in each section will remain nearly constant, regardless of rate of flow, until the flow approaches maximum design flow, when the average level will rise a few inches. Upstream from a change in rate of water delivery, all check-gate settings will change simultaneously, thus responding to a change in water demand by immediately changing the rate of flow all along the aqueduct to the point of delivery.

more pumping when power costs are high than when they are low, and slow response to emergencies.

These control methods will facilitate controlled-volume operation of the aqueduct. Under the controlled-volume system, the volume of water in each check-gated section will remain practically constant at all times, regardless of day-to-day or even hour-to-hour changes in delivery demands. When a change in water delivery is required, pumps at all pumping plants upstream from the point of delivery will be started or stopped and all check gates will be raised or lowered nearly simultaneously.

Through simultaneous regulation of these facilities:

- A change in water demand at any point along the California Aqueduct will be accommodated immediately by changes in operation of aqueduct facilities all the way from the point of delivery to the Delta Pumping Plant. Thus the system will achieve maximum flexibility in customer service.
- All pumping plants along the aqueduct can be scheduled to pump more water during times of the day and week when power costs are low, thus permitting maximum economy in pumping.
- An emergency in any portion of the aqueduct will be met by nearly instantaneous response all along the aqueduct. Operation of the aqueduct will be as safe as human ingenuity can make it.

The California Aqueduct will be operated under local manual control until the remote manual system becomes operational. The step to computer control will be taken when such a system has been shown to be completely reliable and economically justified. If the computer control system comes into use, the other two control systems—local manual and remote manual—will continue to be operable as alternative systems.

The Control System

Simultaneous regulation of aqueduct facilities will be accomplished with the help of what space-age engineers call on-line real-time computer control—to the layman: automation.

Five area control centers, one at Oroville Dam and four others at sites along the California Aqueduct will control project facilities. A single Control Central, in Sacramento, will manage and coordinate the operation of the five area centers. Thus, under this single control will be 138 pumps, 12 generators, 14 pumping generating units, more than 200 check gates, at least 49 major turnouts for customer water delivery, about 9 flow-measurement units, and about 10 water-quality stations. These facilities, spaced at irregular intervals along nearly 700 miles of aqueduct and in the Oroville area, will perform more than 12,000 information-gathering and control functions.

Sensors will continuously read water levels, gate positions, flow rates, status of pumping and generating units, and other essential data throughout the system. During normal operations, each area control center will control all facilities in its area. Sacramento Control Central will monitor all operations, log all operational data, develop overall system water and power schedules, and coordinate operations of the five area control centers. Control Central will ensure operation of the entire State Water Project for maximum efficiency in the production of water and power; in the use of power for pumping; and in the use of men, equipment, and supplies.

California Aqueduct winds past the Dos Amigos Pumping Plant (upper center). The canal is shown here shortly before being filled with water in June 1967.

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State W[...]educts

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State Water Project Aqueducts

The three aqueducts of the State Water Project will convey water from the Sacramento-San Joaquin Delta to water service areas north and south of San Francisco Bay and over the Tehachapi Mountains to Southern California.

The North Bay Aqueduct will deliver water from the Delta to Napa and Solano Counties for municipal and industrial use.

The South Bay Aqueduct delivers water to Alameda and Santa Clara Counties mainly for municipal and industrial use, but some is used for agriculture.

The California Aqueduct will deliver water for irrigation in the southern end of the San Joaquin Valley and for municipal and industrial use to San Luis Obispo, Santa Barbara, and Riverside Counties.

The 11 units of the Delta Pumping Plant will lift as much as 3,800,000 gallons a minute from Clifton Court Forebay to Bethany Reservoir for distribution south through the South Bay and California Aqueducts.

The flow of water through the Californi duct will be regulated by San Luis reserv a capacity of more than 2 million acre-feet winter and spring, when the flow from t is greatest, excess water will be pumped Luis reservoir by the San Luis Pumping- ing Plant. In the summer and fall, when area demands exceed the flow from th water will be released from the reservoir, the pumping-generating plant, to help me delivery requirements.

Much of the water flowing through the nia Aqueduct will be boosted over the T Mountains to Southern California. The 1 of A. D. Edmonston Pumping Plant, wit capacity of 1,500,000 gallons a minute, more than 800 billion gallons a year near feet in a single lift—the highest pump lif United States. Water of the State Water will first reach Castaic reservoir early in 1 Lake Perris, the southern terminus of the a in the spring of 1972.